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Title of the Invention

GAS TURBINE AND GAS TURBINE HIGH TEMPERATURE  
SECTION COOLING METHOD

Inventors

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5 BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a gas turbine and a method of cooling the high temperature section of gas turbine.

10 DESCRIPTION OF PRIOR ARTS

To meet growing demands for electric power in recent years and to combat global warming, it is necessary to increase the capacity and enhance efficiency of gas turbine power generation facilities. Especially in gas turbine power generation facilities where fuels are supplied and burnt with air compressed by a compressor and fed to the combustor and the gas turbine is driven by this combustion gas, large capacity and high efficiency can be achieved by further increasing fuel temperature. In this case, however, the gas turbine for collecting energy of the combustion gas exposed to high temperature will be damaged and a serious accident may occur if it is not cooled. So in gas turbine power generation facilities where combustion gas temperature is high, compressed air and steam are used to cool the high temperature section of gas turbines.

With consideration given to possible pressure loss in the flow path of cooling air, high-pressure air is used as cooling air for cooling the high temperature section of a turbine.

5           In an open cooling gas turbine where cooling air is discharged into the turbine gas path, air extracted from the low-temperature compressor is directly used as cooling air. Air discharged from the compressor is cooled by a cooler, and is used to cool high  
10           temperature sections.

          In a closed cooling type gas turbine where cooling air used to cool the high temperature section of the turbine is collected into the combustor and is used as combustion air, there is pressure loss of cooling air  
15           in the flow path of the turbine high temperature section. So in order to collect cooling air into the combustor, the pressure of air discharged from the compressor must be increased by a boost compressor. If it is increased by the boost compressor, cooling air  
20           temperature will rise. This requires installation of a cooler which adjusts the cooling air temperature to an appropriate level.

          For example, JP A No. 10-196316 discloses a system configuration where air discharged from the compressor  
25           is cooled by a heater exchanger to cool the high temperature section of a turbine.

# SUMMARY OF THE INVENTION

When the turbine is started, the temperature of coolant used by a heater exchanger for cooling the cooling air is low, and cooling air temperature at the heater exchanger outlet is reduced excessively, with the result that mist may occur in the cooling air downstream from the heater exchanger. If mist occurs in cooling air, dust contained in cooling air may be deposited on the wall surface of the cooling flow path. Further, if multiple dust particles are combined to big lumps of dust, a complicated and elaborately formed cooling flow path formed on the turbine high temperature section may be locked. Further, the auxiliary machines constituting the cooling air system may be damaged. Especially the boost compressor constituting the system is a rotary body driven at a high speed. So if mist in air with high-speed air flow is supplied to the boost compressor, it will collide with the impeller at a high speed, with the result that the compressor may be damaged. If the boost compressor is damaged, supply of cooling air to the turbine high temperature section may be suspended, and the turbine high temperature section cooling flow path may be closed due to intrusion of foreign substances. This may cause damages.

Furthermore, deposition of mist on the equipment forming the cooling air system may cause rust inside

the equipment. Such rust will turn into dust generated newly in the cooling air system, and will become a new factor to block the cooling air flow path. For these reasons, if such an event occurs to the cooling air system, cooling air cannot be maintained clean even if the equipment constituting the cooling air system is provided with a high-performance filter capable of separating fine dust is provided. Such a cooling air system is not suitable for cooling the high temperature section of the turbine.

The object of the present invention is to avoid occurrence of mist in the cooling air system of the gas turbine.

A gas turbine according to the present invention comprising a compressor for compressing air, a combustor for mixing air compressed by the compressor with fuel and burning them, and a turbine to be driven by combustion gas burned by the combustor is characterized by further comprising;

a cooling air system for supplying part of air compressed by said compressor to the high temperature section of the turbine;

a heater exchanger for exchanging heat of part of air compressed by the compressor, this exchanger installed on the cooling air system; and

a system for adjusting air temperature on the downstream side of the heater exchanger in conformity

to the operation time of the turbine.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a view representing the high-temperature  
5 section cooling system of a gas turbine as a first  
embodiment of the present invention;

Fig. 2 is a view representing the high-temperature  
section cooling system of a gas turbine as another  
embodiment of the present invention;

10 Fig. 3 is a view representing the high-temperature  
section cooling system of a gas turbine as still  
another embodiment of the present invention;

Fig. 4 is a view representing the high-temperature  
section cooling system of a gas turbine as a further  
15 embodiment of the present invention;

Fig. 5 is a view representing the high-temperature  
section cooling system of a gas turbine as a still  
further embodiment of the present invention;

Fig. 6 is a view representing the high-temperature  
20 section cooling system of a gas turbine as a still  
further embodiment of the present invention;

Fig. 7 is a view representing the high-temperature  
section cooling system of a gas turbine as a still  
further embodiment of the present invention;

25 Fig. 8 is a view representing the high-temperature  
section cooling system of a gas turbine as a still  
further embodiment of the present invention; and

Fig. 9 is a view of the operation status at gas turbine startup as an embodiment of the present invention.

5 DETAILED DESCRIPTION OF THE INVENTION

FIRST EMBODIMENT

The present invention will be described in details with reference to Fig. 1:

Fig. 1 is a drawing representing the configuration  
10 of a gas turbine comprising a turbine high temperature section cooling system.

As shown in the drawing, this gas turbine is equipped with a compressor 1 for compressing air, a combustor 2 for mixing air compressed by the  
15 compressor 1 with fuel and burning them, and a turbine 3 to be driven by combustion gas burned by the combustor 2. It is also provided with a cooling air system for supplying part of air compressed by the compressor 1 to the high temperature section of the  
20 turbine 3.

According to the present embodiment, the cooling air system comprises a heater exchanger 4 for exchanging heat of the air sent from compressor 1, a filter 5 as dust removing means for removing dust from  
25 the air the heat of which is exchanged, a boost compressor 6 for compressing air cleaned by filter 5, and a filter 7 as dust removing means for removing

dust from air compressed by boost compressor 6.

In the air cooling system, the side of compressor 1 will be called upstream side, and the side of turbine high temperature section will be called downstream side hereafter.

Compressed air branched off at the outlet of compressor 1 has its heat exchanged by the heat exchanger 4. Here heat is exchanged so that air temperature at the outlet of the boost compressor 6 on the downstream side reaches an appropriate level for cooling the high temperature section of the turbine. Air of about 500 degrees Celsius, for example, is cooled down to about 100 degrees Celsius by this heater exchanger 4. In other words, it is cooled down to the appropriate air temperature, with consideration given to rise of air temperature in the boost compressor 6.

Cooling air is led from the heat exchanger 4 to the filter 5. This filter removes such foreign substances as mist and dust from air.

Then the pressure of cooling air increase by boost compressor 6. Namely, the boost compressor 6 can boost the pressure to the optimum level as fuel mist air and as turbine high temperature section cooling air. In this case, air temperature rises from about 100 degrees Celsius to about 240 degrees Celsius, for example.



In the present embodiment, a filter 7 or strainer is installed on the downstream side of the boost compressor 6 as well. Air is purified with consideration given to cooling air supplied to the high temperature section of the turbine 3 and fuel oil spray air supplied to the combustor 2.

The cooling air of about 240 degrees Celsius purified in the aforementioned manner is fed to the high temperature section of the turbine to cool the high temperature section of the turbine, where it is heated to a temperature of about 500 degrees Celsius and is supplied to the combustor 2.

In the turbine startup period when the turbine is started by the attached starter, ignited and increased in speed, the temperature of air discharged from the compressor 1 does not increase as compared to the temperature of air sucked in the compressor 1. This air temperature is lower than that of air discharged from compressor 1 at the rated load. Accordingly, air temperature at the heater exchanger outlet is also reduced due to low air temperature at the inlet of the heater exchanger 4.

In such a turbine startup period, mist may occur in cooling air downstream from the heater exchanger 4. If mist occurs in cooling air, dust in cooling air may deposit on the wall surface of the cooling air flow path formed on the high temperature section of the

turbine. Then many fine dust particles contained in cooling air may be combined to form a big lump of dust. If this occurs, a complicated and elaborately formed cooling flow path formed on the turbine high  
5 temperature section may be locked. Blocking of the cooling air flow path may cause insufficient cooling due to insufficiency of cooling air supplied to the high temperature section of the turbine, with the result that the high temperature section of the  
10 turbine may be damaged. Further, the auxiliary machines constituting the cooling air system may be damaged. Especially the boost compressor 6 constituting the system is a rotary body driven at a high speed. So if mist in air with high-speed air flow  
15 is supplied to the boost compressor, it will collide with the impeller at a high speed. This may damage the boost compressor 6.

If the boost compressor 6 is damaged, only insufficient amount of cooling air will be sent to the  
20 high temperature section of the turbine, and this may damage the turbine high temperature section. Furthermore, the damaged boost compressor 6 causes foreign substances to be mixed into cooling air, with the result that the flow path for cooling the high  
25 temperature section of the turbine may be blocked. What is more, the turbine itself may be damaged directly by the foreign substance mixed into cooling

air resulting from the damaged boost compressor 6.

Further, deposition of mist on the equipment forming the cooling air system may cause rust inside the equipment. Such rust will turn into dust generated  
5 newly in the cooling air system, and will become a new factor to block the cooling air flow path for cooling the high temperature section of the turbine.

If the aforementioned event occurs to the cooling air system, cooling air cannot be maintained clean,  
10 even if the equipment constituting the cooling air system is provided with a high-performance filter capable of separating fine dust is provided. Such an air cooling system is not suitable for cooling the high temperature section of the turbine.

15 Here there are different turbine operation periods. Fig. 9 shows the changes in drive speed and load with the passage of time.

The rated drive speed is reached after start of the turbine and increase of speed. Firing occurs  
20 during the period of speed increase. Then the load is gradually increased from the time of parallel-in operation to reach the rated load. Compressed air temperature from the compressor 1 changes under various conditions. It rises from  $T_1$  to  $T_2$ , for  
25 example, as shown in Fig. 9. In the present embodiment, the startup period is defined as the period from the start of the turbine to the arrival of the rated load.

It is preferred to adjust the air temperature in order to avoid occurrence of mist at a desired time during this startup period.

5 To ensure that the cooling air temperature will not be reduced excessively, a system is provided to adjust the air temperature downstream from the heater exchanger 4 in conformity to the turbine operation period.

10 For example, means for heating the coolant used in the indirect type heater exchanger 4 is provided as a system for adjusting air temperature downstream from the heater exchanger 4. Coolant used in the indirect type heater exchanger 4 is heated by the heater 8, and temperature is adjusted to the appropriate cooling air  
15 temperature, whereby preventing mist from occurring due to excessive reduction of the temperature of air at the outlet of the heater exchanger 4. The temperature of the coolant supplied to the heater exchanger 4 is controlled by the temperature of air  
20 close to the outlet of the heater exchanger 4 or on the downstream side, whereby appropriate cooling air temperature can be obtained. It is also possible to get appropriate cooling air temperature using the temperature of air discharged from the compressor 1.

25 However, if the turbine is started and ignition is made to increase the speed by the starter attached to the turbine, the temperature of air at the outlet

(downstream side) of the compressor 1 will rise sufficiently. Even without heating coolant supplied to the heater exchanger 4 for exchanging heat of cooling air branched off from the compressor 1 to cool the high temperature section of the turbine, air at the outlet of the heater exchanger 4 can be adjusted to the appropriate temperature as cooling air without mist occurring therein. Accordingly, by monitoring the temperature of air downstream from the heater exchanger 4 evaluation is made to see if the coolant supplied to the heater exchanger 4 must be heated or not, and adjustment can be made to reach the appropriate cooling air temperature. Alternatively, the temperature of air downstream from the compressor 1 is monitored and evaluation is made in the same manner to see if coolant must be heated or not. In this way, coolant temperature can be managed only at the appropriate time. For example, it is preferred to monitor the temperature measuring instrument for measuring the temperature of air of the cooling air system.

If temperature of air at the outlet of the compressor 1 rises subsequent to firing of turbine or increase of speed, occurrence of mist in cooling air can be reduced by overcooling of the heater exchanger 4. Accordingly, after rise of the temperature of air at the outlet of the compressor 1, coolant is supplied

to the heater exchanger 4 without being heated, and the turbine is operated.

As described above, the present embodiment reduces the amount of mist occurring to the cooling air system.

5       A remarkable effect in reducing mist generation can be expected when a closed type coolant air system is used. Namely, in the closed type coolant air system where cooling air for cooling the high temperature section of the turbine is extracted and air after  
10       cooling is collected and supplied to the compressor 1 outlet or the combustor chamber, pressures at the cooling air extraction position and collection position are on the same level; therefore, air  
15       extracted from the turbine compressor 1 outlet must be increased by the boost compressor the amount  
20       equivalent to the pressure loss in the cooling air flow path, pipe and attached equipment on the high temperature section of the turbine. Air the pressure of which is increased by the boost compressor has its  
25       temperature increased at the same time.

Further, when consideration is given to the heat resistance of turbine parts constituting the collection path, especially the rotor parts, collected air temperature is preferred to be on the same level  
25       as that of the air at the outlet of the turbine compressor. To adjust the cooling air extraction temperature and collected air temperature to the same

level, cooling air extracted from the turbine  
compressor 1 outlet must be cooled by the heater  
exchanger when consideration is given to possible rise  
of cooling air temperature resulting from cooling the  
5 high temperature section of the turbine. As described  
above, in the closed air cooling system, the cooling  
capacity of the heater exchanger is determined to  
ensure that air can be cooled to an appropriate  
temperature without any problem even during the  
10 operation at the rated load, with consideration given  
to both rise of temperature by the boost compressor  
and rise of temperature resulting from cooling of the  
high temperature section of the turbine. Accordingly,  
a greater amount of heat can be exchanged in this  
15 system than in the heater exchanger used in the  
conventional cooling method wherein air after cooling  
is directly discharged into the main stream gas. When  
the turbine is started, temperature of air at the  
outlet of the turbine compressor 1 is lower than  
20 during operation at the rated load. The amount of heat  
exchanged by the heater exchanger used in the closed  
air cooling system is larger than the heater exchanger  
used in the prior art cooling method, as described  
above. Cooling air temperature is unnecessarily  
25 lowered at the heater exchanger outlet. This will  
become a new factor for causing mist in air. Further,  
in the closed air cooling gas turbine, reduction of

temperature of the main stream air resulting from  
discharge of cooling air is held down, and emission  
gas temperature of the gas turbine tends to become  
high. So in order to improve the efficiency of the gas  
5 turbine as a single body and heat resistance of the  
emission gas duct, it is preferred to increase the  
specific pressure of the gas turbine and to keep  
emission gas temperature on the same level as that of  
the prior art gas turbine. Raising the specific  
10 pressure of the gas turbine also increases the  
pressure of cooling air, and the partial pressure of  
the steam contained in cooling air is also increased.  
In this sense, this will promote generation of mist.  
Thus, a remarkable effect in reducing the generation  
15 of mist can be expected when the present invention is  
applied to such a closed type system.

Since the temperature of coolant used in the  
indirect type heater exchanger 4 is adjusted, the  
cooling system is indirectly controlled without direct  
20 control, and this provides a higher reliability of the  
cooling air system. Namely, even if coolant  
temperature adjusting mechanism for this heater  
exchanger 4 is damaged, the cooling air system itself  
is not seriously affected.

25

## SECOND EMBODIMENT

With reference to Fig. 2, the following describes



an example of placing the system 9 for bypassing the heater exchanger 4. When the bypass system 9 is used, temperature of cooling air supplied to the high temperature section of the turbine is adjusted by  
5 mixing between high-temperature cooling air and low-temperature cooling air at the heater exchanger outlet without using heater exchanger 4. This prevents cooling air temperature at the outlet of the heat exchanger from lowering when the turbine is started.

10 The temperature of air at the outlet of the heater exchanger 4 is to an appropriate cooling air temperature by adjusting the flow rate of high-temperature air passing through the bypass system 9 by controlling the opening angle of a valve 9a installed  
15 in the bypass system.

If the temperature of air at the compressor 1 outlet is raised, cooling air temperature can be adjusted to an appropriate level without using the bypass system 9, by controlling the flow rate of the  
20 coolant fed to the heater exchanger 4, even when all the cooling air is fed to the heater exchanger 4. Accordingly, the valve 9a of the bypass system is totally closed.

The present embodiment reduces generation of mist  
25 in the turbine startup period.

Since a bypass system structure is adopted, a simple configuration can be used, and temperature

control range can be extended.

### THIRD EMBODIMENT

In a third embodiment, an auxiliary boiler 10 is  
5 installed to heat coolant supplied to the heater  
exchanger 4 when the turbine is started, as shown in  
Fig. 3. At the time of startup, coolant is heated when  
steam from the auxiliary boiler 10 is fed to the  
heater exchanger 11 installed on the coolant system.  
10 More appropriate temperature management can be ensured  
by controlling the coolant temperature using the  
temperature of air discharged from the compressor. To  
adjust this coolant temperature, the flow rate of  
steam from the auxiliary boiler is adjusted by the  
15 valve 11a.

This avoids excessive reduction of the temperature  
of cooling air supplied to the high temperature  
section of the turbine when the turbine is started.

If the air temperature at the compressor 1 outlet  
20 is raised after turbine startup and firing, heating of  
coolant becomes unnecessary. So the auxiliary boiler  
10 is stopped and coolant is directly fed to the  
heater exchanger 4. Cooling air temperature is  
adjusted by controlling the flow rate of coolant fed  
25 to the heater exchanger 4.

#### FOURTH EMBODIMENT

In a fourth embodiment, a heater 12 is installed to heat coolant fed to the heater exchanger when the turbine is started, as shown in Fig. 4.

5       The coolant system is provided with a water storage tank 13 which is used only when the temperature of air discharged from the compressor is low. A heater is installed on the water storage tank 13 to raise the coolant temperature. Coolant of the  
10       water storage tank 13 is fed by a feed water pump 14 to the heater exchanger 4 for cooling the cooling air from the compressor 1. Coolant temperature can be kept at an appropriate value by control of the temperature of air discharged from the compressor.

15       This prevents cooling air temperature from becoming excessively low when the turbine is started.

      After turbine startup and firing, heating by the heater 12 installed on the coolant system is suspended and valves 14a and 14b are fully closed. Valves 14c  
20       and 14d are fully opened to supply coolant directly to the heater exchanger 4, wherein these valves 14c and 14d are connected to the feed water and drainage system from the coolant system which is shared by  
25       other equipment using coolant installed on the turbine equipment.

#### FIFTH EMBODIMENT

In the fifth embodiment, an evaporator 15 is used for cooling the air discharged from the compressor, as shown in Fig. 5. An auxiliary boiler 16 used only when  
5 the turbine is started in this case.

This allows steam from the auxiliary boiler 16 to be fed inside the evaporator 15 when the turbine is started, whereby coolant temperature inside the evaporator is raised.

10 Water coming the feed water system 17 is turned into steam when heat of cooling air is exchanged by the evaporator 15, and is fed to the steam turbine and other equipment 18. This allows heat to collected, and plant efficiency is improved.

15 Coolant temperature inside the evaporator is adjusted by controlling the flow rate of the steam coming from the auxiliary boiler 16 through the valve 16a. Coolant temperature can be kept at an appropriate value by control of the temperature of air discharged  
20 from the compressor. If temperature of air at the outlet of the compressor 1 is raised after turbine startup and firing, feed of steam from the auxiliary boiler 16 is stopped and heating of coolant inside the evaporator is suspended. Air at the outlet of the  
25 evaporator 15 is used as cooling air for turbine high temperature section.

If the temperature of air at the outlet of the

compressor 1 is raised, temperature of air at the outlet of the evaporator 15 is adjusted by controlling coolant level in the evaporator.

5 This avoids excessive reduction of the temperature of cooling air at the outlet of the evaporator.

#### SIXTH EMBODIMENT

In a sixth embodiment, a heater 19 is installed to raise the temperature of coolant in the evaporator 15  
10 when the turbine is started, as shown in Fig. 6. A water storage tank 20 for heating by a heater 19 and pumps 21 and 22 for circulating coolant are installed. Coolant temperature can be kept at an appropriate level by adjusting the flow rate of coolant  
15 circulating in the water storage tank and by controlling the temperature of air discharged from the compressor.

This avoids excessive reduction of temperature of cooling air at the outlet of the evaporator 15.

20 If temperature of air at the outlet of the compressor 1 is raised after turbine startup and firing, heating by the heater 19 installed on the coolant system is suspended and circulation to the water storage tank is stopped. Circulating pumps 21  
25 and 22 are stopped and valves 22a and 22b fully closed. Coolant is fed to the heater exchanger 4 directly from the coolant feed system 17.

If temperature of air at the outlet of the compressor 1 is raised, temperature of air at the outlet of the evaporator 15 is adjusted by controlling the coolant level in the evaporator.

5

#### SEVENTH EMBODIMENT

In a seventh embodiment, as shown in Fig. 7, the feed rate of the coolant in the evaporator 15 is changed when the turbine is started and coolant level is lowered to the level above the minimum amount of coolant permissible to the evaporator. This avoids excessive reduction of temperature of cooling air at the outlet of the evaporator 15.

After turbine startup, coolant level in the evaporator 15 is increased in conformity to the rise of temperature of air at the outlet of the compressor 1, thereby controlling air temperature. This avoids excessive decrease of temperature of air at the outlet of the evaporator at startup. At the same time, without depending on the operation status, air temperature can be kept at an appropriate level by adjusting the water level through monitoring of the temperature of air at the outlet of the compressor, temperature of air at the outlet of the heater exchanger or temperature of air at the outlet of the booster.

#### EIGHTH EMBODIMENT

In an eighth embodiment, a system 23 for bypassing the evaporator 15 at turbine startup is installed, as shown in Fig. 8. The temperature of air supplied to the high temperature section of the turbine is adjusted by mixing between high-temperature cooling air and low-temperature cooling air at the evaporator outlet using the bypass system 23 without an evaporator.

The above configuration avoids excessive reduction of cooling air temperature at turbine startup.

If the temperature of air at the outlet of the compressor is raised after turbine startup and firing, the valve 23a installed on the bypass system 23 is fully closed to allow all the cooling air to be fed to the evaporator without using bypass system.

As described above, generation of mist in cooling air is prevented by avoiding excessive reduction of cooling air temperature at turbine startup. Reduction of mist generation prevents dust from depositing to the cooling air flow path, and prevents the cooling air flow path from being blocked. At the same time, damage of the auxiliary equipment installed on the system can also be avoided.

The present invention has the effect of reducing mist generation in the cooling air system of a gas turbine at the time of startup.